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Durability of Twisted PP Monofilaments under the Constant Load

Abstract
The durability of two polypropylene monofilaments, of different linear density but twisted to the same degree, were compared together for three different twist degrees under the action of a constant load using the DURAMETR stand devised at the Department of Textile Metrology. The elongation and time at the moment of the sample break were reported. The influence of twist and a high variability in the characteristics tested were observed.

Key words: *durability, creep, constant load, twist, filament, test.*

Introduction

A marked increase in the new generation of fibres, mainly synthetic and inorganic, for technical applications has been observed in the past years [1-6]. Among these fibres, defined as reinforcing or high performance fibres, polypropylene fibres represent the major part [6-7]. The specific work conditions of these types of fibres and the goods made from them, under the action of various types of loads, require new measuring methods and apparatuses for evaluating their properties to be devised [8-10]. The test of durability under a constant load acting over time is one of them. The aim of our investigations was to estimate the influence of twist on the durability of polypropylene monofilaments measured under a constant load.

Measuring Stand

The durability tests were carried out on a new measuring stand, the DURAMETR, which was devised at the Department of Textile Metrology [11]. By means of a computer programme, this stand enables the continuous, simultaneous registration of elongation changes over time of eight samples under a constant load. The values of elongation caused by the acting load and the time related to them were recorded during the tests until the moment when the samples were destroyed.

Material, Samples and Conditions

The tests were carried out on polypropylene monofilaments of circular cross-section shape and nominal diameters of d_n=0.15 mm (symbol PP15) and of d_n=0.30 mm (symbol PP30) made by the 'Stilon' Chemical Fibres Enterprise S.A., Poland.

First of all, the actual linear density Tt in tex was determined on the basis of masses of 500 mm monofilament segments in the number of n=10 (Table 1).

Next, the mean breaking forces F_r in newtons, the elongation at break a_r in mm, and the coefficients of variation of these parameters for the sample length L_o=500±0.5 mm were determined using the Instron tester (model 4204) working with the Series IX Automated Materials Testing System program. The cross-head speed of v=500 mm/min and pre-tension of q=0.5 cN/tex were applied in accordance with the PN-EN ISO 2062:1997 ISO 2062 standard [12]. For both monofilaments fifty tests were carried out. The results are presented in Table 1.

An assumption was made to select the number of turns for the monofilament samples of 500 mm length in such a way that they would be characterised by the following values of the twist parameter: g=0.1, 0.2 and 0.3. The number of turns N in revolutions per 0.5 m were calculated from the following formula:

$$N = 0.5\, g\, s\, /\, (\Pi \cdot d_n) \tag{1}$$

where:
g – assumed value of twist parameter,
d_n– nominal diameter, m,
s – theoretical value of contractor factor

$$s = \ln(1+g^2)/(2 \cdot (\sqrt{1+g^2} - 1)) \tag{2}$$

The twisting of samples in the Z direction under pre-tension of q=0.5 cN/tex was performed using a FY-16 twist tester. After each sample was twisted, the actual values of contraction were noted, the means contraction Δl calculated, and then the experimental mean values of contraction factor s_e were determined from the formula

$$s_e = (500 - \Delta l)/500 \tag{3}$$

The experimental values g_e of the twist parameters were obtained from the formula

$$g_e = 2\,\pi\, d_n\, N\, /\, s_e \tag{4}$$

The results obtained are presented in Table 2.

The durability measurements of non-twisted and twisted monofilaments were carried out for samples of L_1=200 mm length with the use of the DURAMETR under the following constant loads: for PP15, P=7.4 N and 8.8 N; for PP30, P=29.4 and 36.3 N, which corresponded to values of about 70% and 85% of the breaking forces of non-twisted monofilaments. The elongation λ_{ri} in mm, and time t_{ri} in seconds at the moment of the sample break were recorded, and then the mean values and the dispersion of these parameters were calculated. The tests in a number of n=50 were carried out for all variants. The results are presented in Tables 3 and 4. All tests were conducted at standard atmospheric conditions at a temperature of 20±2°C and a relative humidity of 65±2%.

Discussion

The test results indicate a radical influence of twist on the durability of PP monofilaments under constant load. For both the tested monofilaments, the values of elongation at break decrease in function of twist, but they are at similar levels, except for the variant of the highest degree of twisting the PP30 monofilaments. In this latter case, a rapid drop of elongation was noted down to the value of 8.8 mm. The influence of twist is also observed during the action of the constant load up until the moment when the monofilaments break. The values of this indicator decrease with the increase in twist. It should be emphasised that the values of elongation and time obtained are characterised by extremely high levels of dispersion. The coefficients of variation are within the range of 9.5-50.0% in the case of elongation, and within the range of 44.3-155.8% for time. In spite of the realisation of n=50 tests for every variant, the calculated values of relative random errors at the significance level of α=0.05 are very high; for elongations they are within the range of 2.7-14.1%, and for time they are between 12.5% and 44.1%.

In order to compare the obtained values of elongation and time, a statistical analysis of the significance of differences between the mean values was made. The bi-lateral t-Student's and Welch-Aspin's tests at a significance level of α=0.05 were applied in dependence of the existence of the equality of variances', which in each cases was verified by means of the F-Fisher's test at α=0.05. The results of this analysis showed that significant differences exist between the mean values of elongation and time for the PP15 monofilament only for the twist parameters g=0 and g=0.1 for both applied loads. The further increase in twist did not cause any significant differences between the mean values of the tested parameters. For the PP30 monofilament, a significant influence of twist is observed for both constant loads, beginning with the value g=0.1 for elongation, and with g=0.2 for time. Very significant differences are especially

Table 1. Monofilament parameters.

Parameters	Unit	Monofilament	
		PP15	PP30
Actual linear density Tt	tex	15.9	63.6
Mean breaking force F_r	N	10.5	41.7
Coefficient of variation of breaking force v	%	1.9	0.7
Mean elongation at break a_r	mm	114.3	106.7
Coefficient of variation of elongation at break v	%	3.7	3.4

Table 2. Results of twisting for the PP15 and PP30 monofilaments, and for twist parameters g = 0.1, 0.2, and 0.3..

Parameters	Monofilament PP15			Monofilament PP30		
	Twist parameter g =			Twist parameter g =		
	0.1	0.2	0.3	0.1	0.2	0.3
Theoretical contraction factor s	0.997	0.989	0.978	0.997	0.989	0.978
Number of turns N, rev/0.5 m	100	200	300	50	100	150
Experimental contraction factor s_e	0.995	0.984	0.965	0.997	0.987	0.968
Experimental twist parameter g_e	0.095	0.191	0.293	0.094	0.191	0.292

Table 3. Results of durability tests for PP15.

Indicators	Constant load P=7.4 N				Constant load P=8.8 N			
	Twist parameter g =				Twist parameter g =			
	0	0.1	0.2	0.3	0	0.1	0.2	0.3
Mean elongation at break λ_r, mm	35.6	32.4	29.7	28.3	39.6	32.9	32.7	31.5
Coefficient of variation of elongation v, %	16.6	21.2	26.5	29.9	19.0	33.4	9.5	50.0
Mean time to break t_r, s	133.9	76.2	71.3	71.4	37.6	28.3	26.7	24.1
Coefficient of variation of time v, %	147.1	101.8	92.6	155.8	57.3	86.5	44.3	75.4

Table 4. Results of durability tests for PP30.

Indicators	Constant load P=29.4 N				Constant load P=36.3 N			
	Twist parameter g =				Twist parameter g =			
	0	0.1	0.2	0.3	0	0.1	0.2	0.3
Mean elongation at break λ_r, mm	35.8	34.6	31.7	26.5	36.0	32.6	32.7	8.8
Coefficient of variation of elongation v, %	18.6	14.9	17.8	45.4	38.5	32.0	33.0	9.7
Mean time to break t_r, s	307.3	286.8	166.1	71.2	25.8	24.0	21.9	0.5
Coefficient of variation of time v, %	73.8	64.3	88.4	106.4	56.4	48.7	55.9	59.6

evident for the mean values of elongation and time of PP30 monofilaments obtained at g=0.2 and g=0.3. When considering these observations the conclusion can be drawn that, for finer monofilaments, low twist causes an injury to the fibre's internal structure, and a further increase in twist of only a small scale affects the changes to this structure, which (it may be assumed) has the tendency to be on a similar level. The lack of any significant differences between the mean values of elongation and time for higher degrees of twisting may prove the correctness of these considerations. For coarse PP monofilaments, the injury of internal structure appears at a higher number of twist, and probably shows a growing tendency in the function of increase in twist. The values of elongation and time, as well as the extended significant differences between their mean values, indicate this tendency.

The reasons for the changes observed in the measured values and of the especially high dispersions of the parameters obtained by tests, for both non-twisted and twisted monofilaments, may be the heterogeneity of the fibre material, not to mention the variety of structure which depends on the monofilament thickness. Above all, the results obtained show that the number of tested specimens should be much greater in order to obtain a permissible level of random errors. These high variations of elongation and time observed while performing our tests may influence the degree of consistence of values obtained from experiments and from the theoretical calculation on the basis of equations describing the creep of fibres. All these observations should be also taken into account in practical applications of PP monofilaments working under constant loads.

Conclusions

The tests results allow us to present the following final statements:

1. The influence of twist on the durability of PP monofilaments under acting of constant load has been noted.
2. The elongation and time at the moment of break of the finer PP monofilament, subjected to constant loads applied, decrease insensibly as a function of increasing twist.
3. For coarse PP monofilaments, the values of elongation and time decrease to a significant degree, especially at high twists.
4. The tested indicators of monofilament durability are characterised by very high variation; accurate evaluation will be possible after a much greater number of tests are carried out.

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